INVESTIGATION OF PITCHSTONE FINES AS A NOVEL SUPPLEMENTARY CEMENTITIOUS MATERIAL FOR PORTLAND CEMENT BASED CONSTRUCTION PRODUCTS

by

Kirk Vessalas

This thesis is submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

2009

Centre for Built Infrastructure Research
School of Civil and Environmental Engineering
Faculty of Engineering and Information Technology
University of Technology, Sydney

Certificate of Authorship / Originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in this thesis.

K. Vessalas

Kirk Vessalas

Acknowledgments

The author would like to express his gratitude to Prof. Abhi S. Ray, my principal supervisor, for his guidance, advice and support throughout my candidature of this thesis. I would also like to thank Dr. Paul S. Thomas, my co-supervisor, for his suggestions, support and many helpful discussions. The author would further like to thank Dr. Rasiah Sri Ravindrarajah, my alternate supervisor, for his assistance and advice.

In allowing this research to progress, I would like to thank the UTS Challenge Grants Scheme, Centre for Built Infrastructure Research, Perlco Pty Limited (in particular Mr. Paul Joyce and Mr. John Haggman for their enthusiastic support) and Cement Australia Pty Limited (Mr. Des Chalmers) for providing financial support.

For their practical support and suggestions, I would like to thank Dr. Hamish Connan and Dr. Barry Liu for their assistance.

I wish to acknowledge and thank the support and technical assistance of the Faculty of Engineering and Information Technology Civil Laboratories staff especially Mr. Rami Haddad and Mr. Warwick Howse. Similarly, for the Faculty of Science staff, I would like to thank Dr. Norman Booth, Mr. Jean-Pierre Guerbois and Mr. Mark Berkahn for their technical support.

A special thank you is reserved for Ms. Marika Müller. Her support and constant encouragement has made this study a memorable experience. Above all, I must thank my family and friends who have helped and supported me throughout this study.

Abstract

Environmental implications associated with the manufacture and consumption of Portland cement (PC) presents a major challenge to the construction industry. For every tonne of PC manufactured, an equivalent amount of carbon dioxide is generated as greenhouse gas emissions. The use of supplementary cementitious materials (SCMs), also known as pozzolans, for the partial replacement of PC aids the reduction in consumption of PC. SCMs, as environmentally friendly 'green solutions', also provide performance-driven engineering properties of long-term strength development and enhanced durability.

Siliceous and aluminous industrial by-products, such as fly ash (FA), silica fume (SF) and ground granulated blast furnace slag (GGBFS) are used as SCMs to partially substitute PC in order to reduce the consumption of PC in cement-based construction materials. In this study, pitchstone fines (PF) which are the by-product of the production of expanded perlite from a naturally occurring pitchstone deposit in the state of Queensland in Australia are investigated. PF are produced in the crushing stage of the operation where particulates of less than 0.5 mm, which constitute as much as 30% of the pitchstone rock, are discarded causing a potential waste problem.

PF being an amorphous aluminosilicate material was investigated as a potential SCM. Initial investigations on an as received grade of PF, passing 150 μm mesh, produced favourable results for small substitutions of PC (10%); however, a significant water demand was noted in the production of mortars, otherwise the poor workability reduced homogeneous compaction in the moulds and resulted in inconsistent samples with low compressive strength. Two factors, reduced particle size and improved flow, were identified as critical for the improvement of mortar properties. In order to demonstrate this, a fine grade PF with an average particle size 10 μm was prepared. The water demand for the finer grade PF was significant and superplasticiser was added to improve flow. After accelerated ageing at elevated temperature the strength of mortars containing increasing PF additions up to 40% demonstrated increased strength.

In order to investigate the further potential of PF, PF mortars were compared to FA mortars (FA being an industry accepted SCM). The PF was graded to a similar particle size distribution to the FA, and was found to produce similar strength. Based on the ASTM standard criteria for classification as a pozzolan, strength activity index (SAI), a relative measure requiring the strength to be within 75% of the control 100% PC mortar, both PF and FA were found to fulfil the criteria at 20% additions at 7 and 28 days ageing. Mortars with 40% additions approached the SAI criteria only at significantly longer periods of ageing (91 days). A further 10 μm grade PF was prepared by bead milling to investigate the standard water curing of PF mortars and compared to a similarly graded FA. Both mortar types produced with 20% and 40% addition levels significantly surpassed the strength of the control PC mortars.

The susceptibility of PF and FA mortars to sulphate attack was investigated by immersing mortar cubes in deionised water and 1 M sodium sulphate. The degree of sulphate attack was monitored by mass gain and compressive strength measurement after 182 days of immersion. The 100% PC control mortar showed significant susceptibility with a large increase in mass gain and a reduction in strength. Both the PF and FA substituted mortars were found to be significantly more resistant to the sulphate solution with lower mass gains and significant improvements in strength relative to the control mortar in deionised water. In the PF and FA mortar samples, ettringite was identified by XRD analysis suggesting that its formation mitigated the effects of sulphate attack.

The investigation of PF as a pozzolan particularly in comparison to FA demonstrated that PF in mortar and concrete exhibited the positive attributes of strength and durability required. This experimental investigation proved that PF may be used as a SCM for the partial replacement of PC. From an engineering perspective, PF, which are hitherto unknown as a SCM for PC-based construction materials, are a viable option for adoption in the manufacture of PC-based construction materials, eventuating in value added benefits of strength improvement and increased resistance to chemical attack. Since the PF studied are currently a by-product of mining, the use of this naturally occurring SCM also helps mitigate the environmental impact at the mine site.

Table of Contents

List of Abbreviations

10CA	10 mm Coarse Aggregate
20CA	20 mm Coarse Aggregate
AAC	Autoclaved Aerated Concrete
AS	Australian Standards
ASTM	American Society for Testing and Materials
C_c	Calcite
CS	Coarse Sand
C-A-S-H	Calcium Aluminate Silicate Hydrate
C_2S	Dicalcium Silicate
C_3A	Tricalcium Aluminate
C_3S	Tricalcium Silicate
C_4AF	Tetracalcium Aluminoferrite
CH	Calcium Hydroxide (Portlandite)
C-S-H	Calcium Silicate Hydrate
DTA	Differential Thermal Analysis
DTG	Differential Thermogravimetry
DTGA	Differential Thermogravimetric Analysis
DW	Deionised Water
E	Ettringite
EPA	Expanded Perlite Aggregate
EPP	Expanded Perlite Powder
FA	Fly Ash
FEPA	Fine Expanded Perlite Aggregate
FESEM	Field Emission Scanning Electron Microscope
FS	Fine Sand
GGBFS	Ground Granulated Blast-Furnace Slag
HPFA	HI-POZZ Fly Ash
KFS	Kurnell Fine Sand
ICCD	International Centre for Diffraction Data
ITZ	Interfacial Transition Zone

JCPDS	Joint Committee on Powder Diffraction Standards
L	Larnite
L_{dx}	Dehydroxylation Mass Loss
L_{dc}	Decarbonation Mass Loss
LOI	Loss on Ignition
LWAC	Light-Weight Aggregate Concrete
NPP	Natural Perlite Powder
P	Portlandite
P1	İzmir Perlite Powder
P2	Erzincan Perlite Powder
PA	Pumice Aggregate
PC	Portland Cement
PF	Pitchstone Fines
PFA	Pitchstone Fine Aggregate
PP	Perlite Powder
PSA	Particle Size Analyses
Q	Quartz
RH	Relative Humidity
SCC	Self Compacting Concrete
SE	Secondary Electrons
SEM	Scanning Electron Microscopy
SF	Silica Fume
SS	Sodium Sulphate
SSD	Saturated Surface Dry
TG	Thermogravimetry
TGA	Thermogravimetric Analysis
W	Water
w/b	Water/Binder
w/c	Water/Cement
w/cm	Water/Cementitious Material
WR	Water Requirement
wt. %	Weight Percent
XRD	X-ray Diffraction
XRF	X-ray Fluorescence

List of Figures

List of Tables